SWITCHABLE COUPLING

This invention relates to the coupling of two unpolarised light inputs.

Throughout this specification and claims the word "light" is used to cover any form of electromagnetic energy that can be transmitted within a waveguide.

Electro-optical switches are known which use the properties of a birefringent material, such as a liquid crystal layer, to switch unpolarised light from one multimode fibre to another. For instance, the April 1980 edition of OPTICS LETTERS, volume 5, number 4, pages 147-149, reports details of a high efficiency electro-optic liquid crystal device by R A Soref and D H McMahon of Sperry Research Centre, Sudbury, Massachusetts, USA. This disclosure teaches that a novel double-pass structure can enable nearly 100% of unpolarised light signals to be exchanged between pairs of multimode fibres in response to electrical control voltages. However this proposal does not enable two unpolarised light inputs to be coupled, that is switched into the same outlet port.

Liquid crystal exists in a nematic phase where its molecules line up in a common direction but have no specific positional orientation. This molecular orientation gives rise to the liquid crystal medium being anisotropic in character, that is having material properties such as optical and electromagnetic characteristics, that are direction dependent.

One of its anisotropic properties is its refractive index which leads to a double refraction (or birefringent) characteristic. As a consequence, when unpolarised light is incident on the surface of liquid crystal, different refractive indices act on the two polarisation components of the incident light. These polarisation components are:

1. A component acting perpendicular to both the direction of propagation and the liquid crystal surface, and .
2. A component normal to the first component but still acting perpendicular to the direction of travel.

The two refractive indices are termed the ordinary index n_o and the extraordinary index n_E. If the refractive index of the waveguide medium adjoining the liquid crystal surface is n_1, then

$n_1 >> n_o$

$n_1 \approx n_E$ (but slightly larger)

If the angle of incidence is greater than the critical angle due to n_o, but less than the critical angle due to n_E, one polarisation component will be refracted through the liquid crystal whilst the other polarisation component will be totally reflected. Due to this characteristic, liquid crystal can be used as a polarisation splitter device which will split incident unpolarised light into refracted and reflected polarised components.

When an electric field is applied to a liquid crystal cell, the dipole nature of the molecules causes their rotational transition with the result that the values of the ordinary and the extraordinary refractive indices, relative to the incident ray, are exchanged. Consequently the previously refracted polarised component is reflected, and the previously reflected polarised component is refracted. Due to this characteristic, liquid crystal in conjunction with an electric field device is capable of switching two polarised lightrays .

The present invention is concerned with the provision of both an optical coupler and a method which enables the coupled unpolarised light inputs to be switched into the same outlet port.

According to one aspect of the invention, a switchable coupler has:-

a first waveguide defining

an inlet port for a first unpolarised light input and

a first outlet port,

a second waveguide defining

an inlet port for a second unpolarised light input and

a second outlet port,

a polarisation splitter device positioned between the waveguides to split the first unpolarised light input and the second unpolarised light input into respective refracted and reflected polarised components,

the waveguides being arranged to transmit

the refracted and reflected polarised components of the first light input by total internal reflection in the direction of the first outlet port, and

the refracted and reflected polarised components of the second light input by total internal reflection in the direction of the second outlet port,

a first electro-optical switch positioned in the paths of the refracted and reflected polarised components of the first light input,

the first electro-optical switch being operable to recombine the refracted and reflected polarised components of the first light input and to switch these combined components towards the second outlet port, and

a second electro-optical switch positioned in the paths of the refracted and reflected polarised components of the second light input,

the second electro-optical switch being operable to recombine the refracted and reflected polarised components of the second light input and to switch these combined components to the first outlet port.

In this manner the first unpolarised light input can alternatively be switched into the same outlet port as the second unpolarised light input. Thus the two unpolarised light inputs are coupled together and can also be switched between two outlet ports.

The polarisation splitter device preferably includes liquid crystal positioned between the waveguides. In this case the liquid crystal may define

two separate cells, one liquid crystal cell serving to split the first unpolarised light input, and the other liquid crystal cell serving to split the second unpolarised light input.

The, or each, electro-optical switch preferably includes liquid crystal positioned between the waveguides, and an electric field device is provided to generate an electric field across the liquid crystal to operate the electro-optical switch, or switches. In this case the liquid crystal preferably defines two separate cells, one of these liquid crystal cells forming part of each electro-optical switch.

According to another aspect of the invention, a method of coupling first and second inputs of unpolarised light comprises:-

splitting the first and second inputs into respective refracted and reflected polarised components,

transmitting the refracted and reflected components of the first input to a first electro-optical switch operable to recombine the refracted and reflected components of the first input and to switch the recombined output from a first outlet to a second outlet,

transmitting the refracted and reflected components of the second input to a second electro-optical switch operable to recombine the refracted and reflected components of the second input and to switch the recombined output from the second outlet to the first outlet, and

selecting the operation of the first and second electro-optical switches to couple the first and second inputs into either the first outlet or the second outlet.

The invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Figure 1 is an enlarged side elevation of an optical coupler as taught by this invention;

Figure 2 is a diagram illustrating the ray passage of a first unpolarised light input to a first outlet port;

Figure 3 is a diagram illustrating the ray passage of a second unpolarised light input to the first outlet port;

Figure 4 combines the information shown in Figures 2 and 3 to illustrate how the first and second unpolarised light inputs are coupled into the first outlet port;

Figure 5 is a diagram illustrating the ray passage of the first unpolarised light input to a second outlet port;

Figure 6 is a diagram illustrating the ray passage of the second unpolarised light input to the second outlet port, and

Figure 7 combines the information shown in Figures 5 and 6 to illustrate how the first and second unpolarised light inputs are coupled into the second outlet port.

The same reference numerals are used throughout the drawings to denote equivalent features and only points of difference will be described.

With reference to Figure 1, an optical coupler 10 comprises two polarisation splitter devices 11 and 12, and two electro-optical switches 13 and 14, all sandwiched between an upper waveguide 15 and a lower waveguide 16. The adjectives "upper" and "lower" only refer to the relative positions of the waveguides 15 and 16 as shown in the drawings and do not imply any orientation of the optical coupler 10 which can operate in any orientation.

The polarisation splitter devices 11,12 are formed by respective liquid crystal cells 17 and 18 positioned between the waveguides 15 and 16 as shown.

The electro-optical switches 13, 14 are also formed by respective liquid crystal cells 19 and 20 positioned between the waveguides 15 and 16 as shown. The opposite sides of the liquid crystal cells 19 and 20 are provided with electrodes 21, 22 which can be selectively connected by closing respective switches 23, 24 to apply a potential difference V whereby an electric field can

be applied to the selected electrodes 21 or 22 to operate the associated electro-optical switch 13 or 14. The electrodes 21, 22, the switches 23, 24 and the potential difference V constitute an electric field device 25 for generating an electric field through the liquid crystal cells 19 and/or 20 to cause the values of the ordinary refractive index and the extraordinary refractive index to be exchanged.

Upper waveguide 15 is formed from a glass core which defines an inlet port 31 for a first unpolarised light input and a light outlet port 32. The lower waveguide 16 is similarly formed from a glass core which defines an inlet port 41 for a second unpolarised light input and a light outlet port 42. In the drawings the construction of the waveguides 15 and 16 is simplified by only illustrating their glass cores. However, it will be understood that the waveguides 15 and 16 would be provided with the usual exterior cladding to promote complete total internal reflection, this cladding being omitted to define transparent windows for the inlet ports 31 and 41 and for the outlet ports 32 and 42. Similarly transparent windows will be left unclad above and below the liquid crystal cells 17, 18, 19 and 20 to permit light to pass between the waveguides 15 and 16 as will shortly be described. The glass, from which the waveguide cores are manufactured, has an appropriate refractive index relative to the liquid crystal material. The waveguide cores may be manufactured from other appropriate materials dependent on the wavelength of the electromagnetic radiation.

Figures 2 to 7 illustrate the passage of a first unpolarised light input A and a second unpolarised light input B through the waveguides 15 and 16, the unpolarised beams being shown by heavy full lines, reflected polarised beams being indicated by lighter dashed lines, and refracted polarised beams being indicated by lighter dotted lines.

In Figure 2 the first unpolarised light input A is seen entering the inlet port 31 and being transmitted by complete total internal reflection within the upper waveguide 15 to impinge on the splitter device 12 where it is split into a refracted polarised component A_F and a reflected polarised component A_L. The reflected component A_L is transmitted within the upper waveguide 15 by total

internal reflection to exit through outlet port 32, whilst the refracted polarised component A_F passes through the liquid crystal cell 18 and is transmitted within the lower waveguide 16, by total internal reflection, to exit through outlet port 32, having passed through the liquid crystal cell 20. Thus the first unpolarised light input A is transmitted through the switchable coupler 10 to exit through the outlet port 32 as light output A_T comprising the two polarised components A_L and A_F of the first unpolarised light input A.

In Figure 3 the second unpolarised light input B is seen entering the inlet port 41 to impinge on the splitter device 11 where it is split into a refracted polarised component B_F and a reflected polarised component B_L. The refracted polarised component B_F is transmitted within the upper waveguide 15 by total internal reflection to impinge on the upper surface of the electro-optical switch 13, whilst the reflected polarised component B_L is transmitted within the lower waveguide 16 by total internal reflection to join the refracted polarised component B_F, having passed through the liquid crystal cell 19. As shown, a potential difference V has been applied to the electrodes 21 causing the polarised components B_F and B_L to recombine and exit through outlet port 32 as light output B_T which is identical with light input B

Figure 4 combines the information provided by Figures 2 and 3 and shows that the application of a potential difference V across the liquid crystal cell 19 operates the electro-optical switch 13 to cause the second light output B_T to exit through outlet port 32 with the light output A_T. In this manner the two separate light inputs A and B have been coupled together to pass through the same outlet port 32.

In Figure 5 the first unpolarised light input A is transmitted through the switchable coupler, as far as the liquid crystal cell 20, in exactly the same manner as already described with reference to Figure 2. However the liquid crystal cell 20 has been activated by applying a potential difference V to the electrodes 22 to allow the reflected component A_L to pass through the liquid crystal cell 20 and to cause the polarised components A_L and A_F to recombine and exit through the outlet port 42 as light output A_T which is identical with light input B.

In Figure 6 the second unpolarised light input B is transmitted through the switchable coupler 10, as far as the liquid crystal cell 19, in exactly the same manner as already described with reference to Figure 3. However, no potential difference is applied to the liquid crystal cell 19 which reflects the reflected polarised component B_L to exit through outlet port 42. The refracted polarised component B_F passes through the liquid crystal cell 19 to exit through the same outlet port 42. In this manner the two polarised components B_F and B_L both exit the outlet port 42 as light output B_T.

Figure 7 combines the information provided by Figures 5 and 6 and shows that the application of a potential difference V across the liquid crystal cell 20 operates the electro-optical switch 13 to cause the first light output A_T to exit through outlet port 42 with the light output B_T. In this manner the two separate light inputs A and B have been coupled together to pass through the same outlet port 42.

From a comparison of Figures 2 and 5, it will be appreciated that, simply by applying the potential difference V to the terminals 22 of the electro-optical switch 14, the first unpolarised light input A can be switched from outlet port 32 to outlet port 42. Similarly a comparison of Figures 3 and 6 show that the application of potential difference V to the terminals 21 of the electro-optical switch 13 will switch the second unpolarised light output B from the outlet port 42 to the outlet port 32.

More importantly, from a comparison of Figures 4 and 7, it will be appreciated that the application of the potential difference V to operate either of the electro-optical switches 13 or 14 will couple the two unpolarised light inputs A and B together and will also control from which of the outlet ports 32 or 42 the coupled light outputs will exit.

This invention is particularly useful when applied to a fibre optic signal handling system in which the output intensity of the optical coupler 10 is the primary consideration.

In the drawings, the light outputs A_T and B_T are shown parallel but separated, their separation assisting the description of the various light paths. If desired, the configuration of the waveguides 15 and 16, and also the relative positions and the number and sizes of the liquid crystal cells 17, 18, 19 and 20 may be adjusted to minimise the separation of the light outputs A_T and B_T.

If desired, other optical or electro-optical devices may be provided for recombining any polarised components of the light outputs A_T and B_T, and/or for directing the light outputs A_T and B_T.

The liquid crystal material has been shown as separate cells 17, 18, 19 and 20 to avoid any edge effects. However, if desired, any or all of the liquid crystal cells may be combined so that they are dedicated zones within a larger cell of liquid crystal, provided that their function is not disturbed by any edge effect.